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3D Numerical Simulation on Annular Diffuser Temperature Distribution Enhancement by Different Twist Arrangement

Ehan Sabah Shukri, Wirachman Wisnoe

***Abstract*—**The influence of twist arrangement on the temperature distribution in an annular diffuser fitted with twisted rectangular hub is investigated. Different pitches (Y = 120 mm, 100 mm, 80 mm, and 60 mm) for the twist arrangements are simulated to be compared. The geometry of the annular diffuser and the inlet condition for the hub arrangements are kept constant. The result reveals that using twisted rectangular hub insert with different pitches will force the temperature to distribute in a circular direction. However, temperature distribution will be enhanced with the length pitch increases.

***Keywords*—**Numerical simulation, twist arrangement, annular diffuser, temperature distribution, swirl flow, pitches.

I. Introduction

TEMPERATURE distribution in annular diffusers fluid flow have been applied in many engineering applications such as gas turbines, compressors, pumps, wind tunnels, etc. The thermal performance in an annular diffuser is quite different than the thermal performance in an axial diffuser because of the hub existence. Both kinds play an important role in many fluid machines to convert kinetic energy into pressure energy. In thermal applications that adopt temperature distribution such as combustion process and boilers, it is essential to use swirl generators that provide a rotational flow around an axis parallel to the flow direction. Twist arrangements are one important group of swirl generator which mostly applied for heat transfer improvement. It is an efficient method used to increase the heat transfer rate and to enhance temperature distribution through diffusers and pipes without the need to add any external power. Effects of different twisted tape geometry were reported by Eiamsa-ard et al. [1], [2]. They obtained the influences of circular-ring turbulators (CRT) and twisted tape (TT) swirl generators on the heat transfer enhancement, pressure drop and thermal performance characteristics in a round tube. Three different pitch ratios of the (CRT) and three different twist ratios of the (TT) were introduced. The experimental results reveal that the heat transfer rate, friction factor and thermal performance factor of the combined (CRT) and (TT) are considerably higher than those of (CRT) alone. For the range examined, the increases of mean Nusselt number, friction factor and thermal performance, in the tube equipped with combined devices, respectively, are 25.8%, 82.8% and 6.3% over those in the tube with the (CRT) alone [1]. In another work, the heat transfer enhancement using twisted tapes with alternate axes (TA) at different alternate lengths was investigated [2]. Twisted tapes with both uniform and non-uniform alternate lengths (TAs and N-TAs) were evaluated in comparison with typical twisted tape (TT) using different twist length ratios. Results indicated that the twist length ratio (l/y = 0.5), giving the highest heat transfer rate as well as the maximum thermal performance factor.

E. S. Shukri and W. Wisnoe are with Mechanical Engineering Department, University Technology MARA (UiTM), 40450 Shah Alam, Selangor, Malaysia (e-mail: ehansabah@yahoo.om, wira_wisnoe@yahoo.com).

Different twist arrangements have been studied by Ehan et al. [3], [4]. Heat distribution and flow behaviors in an annular diffuser with twisted rectangular hub numerically simulated [3]. The study was conducted with three different twist ratios (Y/W). The results showed that temperature distribution increased as twisted ratio (Y/W) decreased. Temperature distribution in an annular diffuser equipped with helical tape hub and a twisted rectangular hub were numerically simulated [4]. Different twist ratios for the annular diffuser with both helical tape hub and twisted rectangular hub were compared. Result obtained that using both helical tape hub and twisted rectangular hub forced the temperature to distribute in a helical direction. However the results showed clearly that helical tape insert gave better enhancement.

Tan et al. [5] studied different geometry influence of twisted oval tube in the shell side of heat exchanger. Results reflected that Nusselt number and friction factor both increased with the increasing of length and aspect ratio. It concluded that the overall heat transfer performance of the shell side increased with the increasing of the aspect ratio.

Chang et al. [6], [7] examined the spiky ribbed twist tapes with and without V-notches at forward and backward flow conditions as the newly devised heat transfer enhancements elements for tubular heat exchangers to discover their competitive thermal performances for various design applications. Results conducted with all these different geometry achieved that the thermal propertied will be enhanced [6]. Study has been revealed the heat transfer and pressure drop characteristics of laminar and turbulent tubular flows enhanced by five types of modified twist tapes with their thermal performance factors compared by the plain tube references and the baseline tubular flow references with a conventional or spiky twist tape insert. They compared the results with those reported for other types of twisted tapes in the literature; the tested V-notched spiky twisted tape generally offered the highest heat transfer enhancement impacts with favorable thermal performance factors performances.

Mogaji et al. [8] conducted an experimental study of heat transfer coefficient and pressure drop during two-phase flow of R134a in a horizontal tube containing twisted-tape insert. After testing different twist ratios the results proved that the use of twisted tape was suitable when it was applied to the high vapor quality region of the evaporator and under mass velocities higher than 150 kg m^2/s.

Twist arrangements insert are one of the most favorable passive techniques because they are inexpensive and can be easily employed to the existing system. In the present work, twisted rectangular hub insert is added during an annular diffuser. The aim is to study the influence of temperature distribution inside annular diffuser fitted with twisted rectangular hub. In this article the effect of different pitches of the twisted rectangular hub on temperature distribution are simulated and analyzed by means of CFD software. Simulations are carried out at the same inlet conditions with Reynolds number around 6.918×10^4 based on the inlet diameter of the diffuser.

II. Simulation Facility and Procedure

A. Annular Diffuser with Twisted Rectangular Hub Geometry

The annular diffuser with twisted rectangular hub geometry is shown in Fig. 1. Four different twist pitches (*Y* = 120 mm, 100 mm, 80 mm, and 60 mm) are simulated. Fig. 2 shows CAD drawing for the twisted rectangular hub with different pitches.

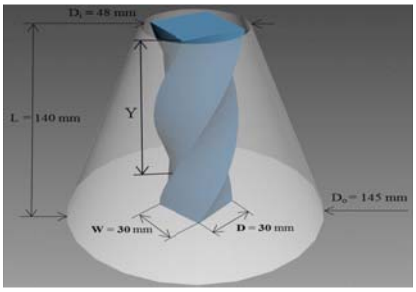

Fig. 1 Annular diffuser geometry with twisted rectangular hub

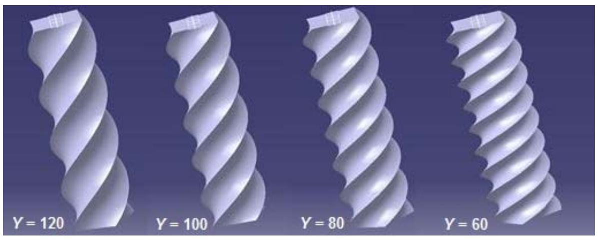

Fig. 2 CAD drawing for different pitches for twisted rectangular hub

B. Simulation Model

Numerical simulations of temperature distribution inside an annular diffuser fitted with twisted rectangular hub are carried out in the present work. The commercial software Numeca Fine/Open v.3.1 is chosen as the Computational Fluid Dynamics (CFD) tool for this work. The numerical analyses are performed in three dimensional domains applying standard k-ε model as a turbulence model. Standard k–ε turbulence model is allowed to predict the heat transfer and fluid flow characteristics. This turbulence model has been successfully applied to flow with engineering applications including internal flow [9]. The turbulence kinetic energy k, and its rate of dissipation ε, isobtained from the following transport equations [10]:

$$k = 0.002\,(u)^{2}$$
$$\varepsilon = (k)^{1.5} / 0.3\,D$$

where, u is the inlet velocity and D is the inlet diameter. Fig. 3 shows mesh generation of an annular diffuser fitted with twisted rectangular hub. Table I shows the dimensions of the tested diffusers and typical values of boundary conditions are given in Table II.

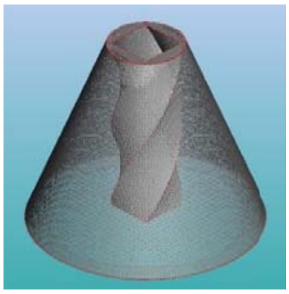

Fig. 3 Mesh generation of an annular diffuser with twisted rectangular hub

TABLE I
ANNULAR DIFFUSER DIMENSIONS

Symbol	Parameters	dimensions
D_i	Inlet diameter	48 mm
D_o	Outlet diameter	145 mm
L	Length	140 mm
d	Hub diameter	30 mm

TABLE II
BOUNDARY CONDITIONS

Symbol	Parameters	Values
P_i	Inlet pressure	289000 pa
V_i	Inlet velocity	49.12 m/s
T_{in}	Inlet temperature	870.266 K
ν	Kinematic Viscosity	9.421×10^{-5} m^2/s
Re	Reynolds Number	6.918×10^4

C. Heat Source

For this study, a spherical heat source of 10 kW with the radius of 0.005 m is put in the diffuser at 23 mm from the longitudinal axis, 21 mm downstream of the inlet section. It is with the beginning of the twist arrangement.

The unsymmetrical location of the heat source is purposely chosen in order to better observe the swirling motion.

III. Results and Discussion

A. Testing Sections

Temperature distribution is numerically obtained for an annular diffuser fitted with twisted rectangular hub for different pitches (*Y*). The numerical analysis for the annular diffuser is obtained for three cutting sections.

Fig. 4 shows the three cutting sections along the radial direction of the annular diffuser at 30 mm (section 1-1), 70 mm (section 2-2), and 110 mm (section 3-3).

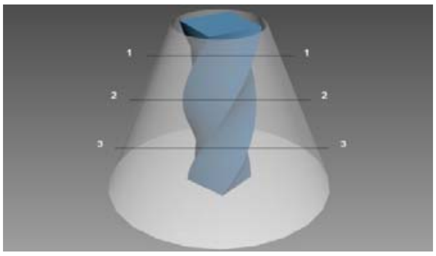

Fig. 4 Three cutting sections in the radial direction of the annular diffuser

B. The Influence of Different Pitches (Y)

Pitch length is an important factor to indicate the enhancement of temperature distribution. Therefore simulation results of an annular diffuser with twisted rectangular hub will be discussed for different pitches (*Y* = 120 mm, 100 mm, 80 mm, and 60 mm) for three cutting sections in the radial direction.

Figs. 5-8 show the influence of twist arrangement existence on the temperature distribution. The testing static temperature range is presented from 450 K (dark blue) to 3500 K (red).

Fig. 5 displays the impact of the twist arrangement insert on the temperature during the flow with pitch (*Y* = 120 mm). Section 1-1 indicates that the temperature is almost at the heat source location so it is around (3490 K). The temperature will be spread more in section 2-2 with more colored area. In section 3-3 the spread area of temperature shown to be more but with lighter blue that means less temperature degrees.

In Fig. 6 which tests pitch (*Y* = 100 mm) it can be seen that the phenomenon appears to be similar. The temperature starts to distribute from section 1-1 until section 3-3 and the colored area becomes bigger during sections. Results obtain that the existence of twist arrangement force the temperature to move in the radial direction and in the direction of the flow as well.

Pitch (*Y* = 80 mm) represents in Fig. 7. It reveals that the temperature starts to distribute in the both directions from section 1-1 until section 3-3 and the colored area starts to spread at the three sections. Results show that distribution area starts to increase through the sections.

Twist pitch (*Y* = 60 mm) shows in Fig. 8, the temperature starts to distribute in the radial direction and in the direction of the flow from section 1-1 until section 3-3. Results show that distribution area starts to increase through the sections.

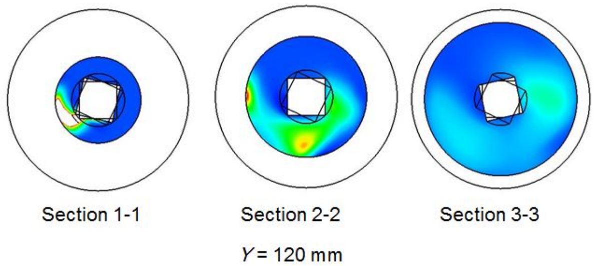

Fig. 5 Three sections for the tested diffuser with pitch (*Y* = 120 mm)

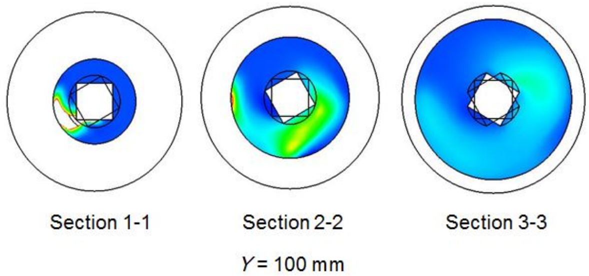

Fig. 6 Three sections for the tested diffuser with pitch (*Y* = 100 mm)

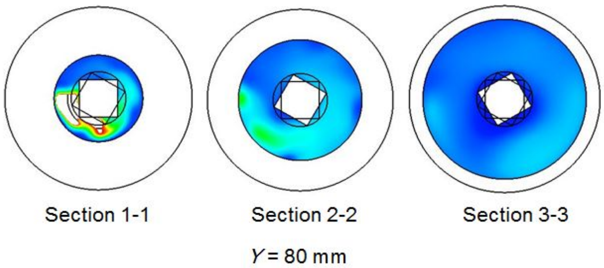

Fig. 7 Three sections for the tested diffuser with pitch (*Y* = 80 mm)

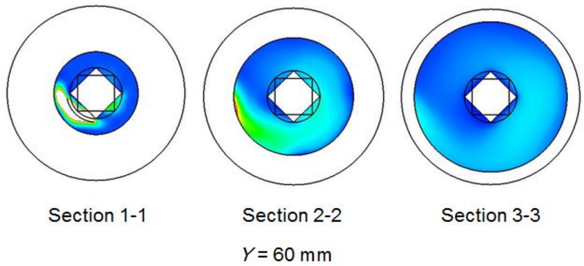

Fig. 8 Three sections for the tested diffuser with pitch (*Y* = 60 mm)

C. Effect of Twisted Rectangular Hub with Different Pitches at the Outlet Section

Figs. 9-12 explain the relation between static temperature and different radial distance (*X/L*) with four different pitches (*Y* = 120 mm, 100 mm, 80 mm, and 60 mm) in an annular diffuser fitted with twisted rectangular hub at the outlet section (*L* = 135 mm).

Results show the temperature distribution behavior in this section for these different pitches. They are used for comparative purposes. Simulation outcomes indicate that temperature will follow the radial direction in all twist arrangements but in different manner.

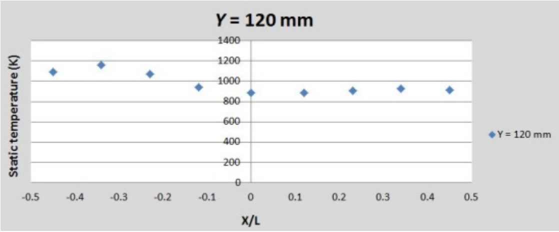

Fig. 9 Temperature distribution in the outlet section (L = 135 mm) for pitch (Y = 120 mm)

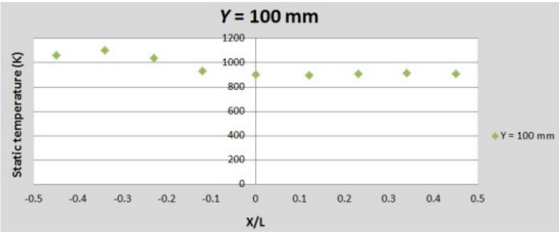

Fig. 10 Temperature distribution in the outlet section (L = 135 mm) for pitch (Y = 100 mm)

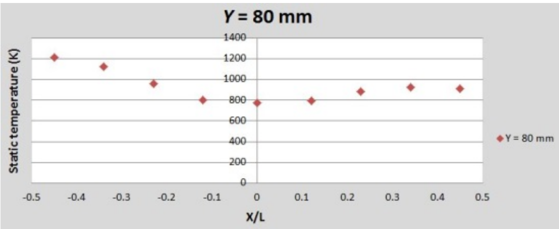

Fig. 11 Temperature distribution in the outlet section (L = 135 mm) for pitch (Y = 80 mm)

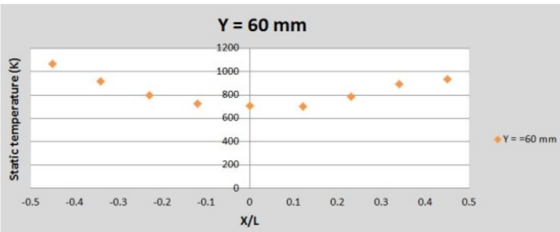

Fig. 12 Temperature distribution in the outlet section (L = 135 mm) for pitch (Y = 60 mm)

D.Comparison of Different Pitch Effect

Comparison of using different pitches for the twisted rectangular hub of an annular diffuser reveals clearly that the insert of the twist arrangements will affect the temperature distribution in positive way and the temperature will distribute in several directions.

Fig. 13 shows the effect of four different pitches (Y = 120 mm, 100 mm, 80 mm, and 60 mm) on the temperature distribution at the outlet section. It can be obtained that the diffusion area is wider in the outlet section for all the pitches.

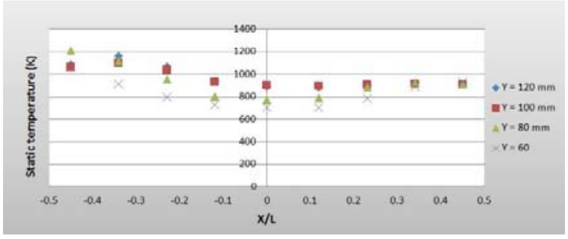

Fig. 13 Temperature distribution in the outlet section (L = 135 mm) for different tested pitches

IV. Conclusion

In the present study, the influences of twisted rectangular hub on temperature distribution are investigated for an annular diffuser with four different pitches. The tested pitches are simulated with heat source of 10 KW. The numerical simulation using CFD approach is used to provide information about temperature distribution. The simulation results show the dependence of the temperature distribution on the twist arrangement. The numerical study confirms that the temperature will follow circular motion due to the present of the twist arrangement insert. The simulation results achieve that:

1) Temperature distribution characteristics are investigated with four pitches. The existence of twisted rectangular hub causes distribution area to be increased from section 1-1 until outlet section.
2) The relation between static temperature and different radial distance (*X/L*) with four different pitches (*Y*) in Figs. 9-12 reveals that the existence of the twist arrangement insert will help the temperature to distribute in the radial direction of the flow.
3) Comparison of the simulation results show clearly that using different pitches will distribute the temperature, however the results detect that the distribution appear to be better with high pitches.

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